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Overview of Gearbox Reliability Collaborative Condition Monitoring

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Outline

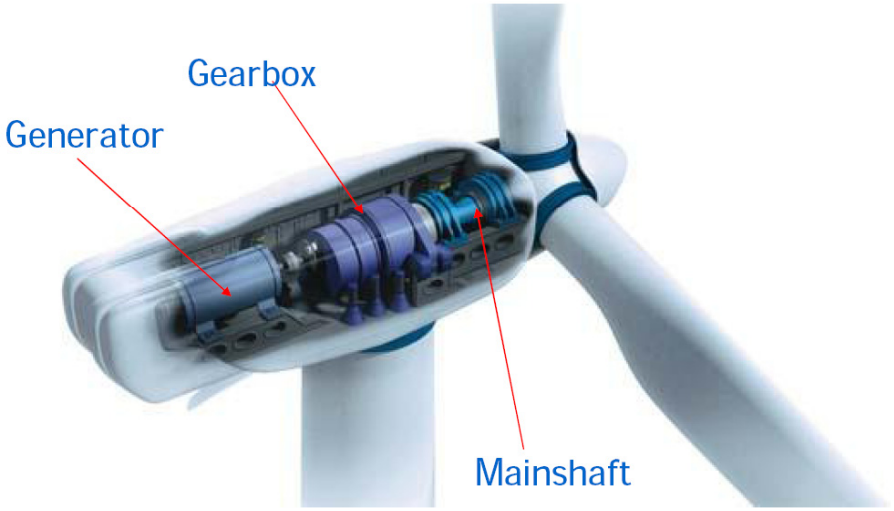
- Introduction
  - Benefits of Condition Monitoring (CM)
  - Typical wind turbine CM practices
  - Scope and Objectives of CM under Gearbox Reliability Collaborative (GRC)
- **Approach and rationale**
- Selected CM systems and reasoning
- CM implementation for dynamometer (Dyno) and field tests
- **Preliminary Dyno test results**
- Planned data analysis and future research

Introduction: Benefits of CM

- Early deterioration detection to avoid catastrophic failure
- Accurate evaluation of damage enabling cost effective maintenance planning
- Root-cause analysis leading to improved operational strategy

Introduction: Wind Turbine CM

- Components
  - Blade
  - Drivetrain
- Techniques
  - Acoustic emission (AE) analysis
  - Vibration analysis
  - Lubricant CM



Source: SKF (with permission)

- Typical Practice
  - Integration of vibration or AE (e.g., stress wave) with oil CM

Introduction: Scope and Objectives

- Scope under GRC: wind turbine drivetrain
- Objectives:
  - Establish a CM baseline for both run-in and typical field operations
  - Early detection of failure or component deterioration
  - Root-cause analysis by correlating CM outputs with operational conditions (e.g., rpm, torque) and gearbox internal dynamics (e.g., displacement, strain)
  - Theoretical or simulation-based model validation.

Approach & Rationale

- Approach
  - A combination of acoustic emission (specifically, stress wave), vibration and lubricant CM techniques.
- Rationale
  - Each technique has its own strengths and limitations.

Approach & Rationale (*Cont.*)

Condition	Lubrication CM	Vibration CM	Correlation
Machine Unbalance	Not Applicable	Strength	Vibration program can detect an unbalance condition. Lube analysis will eventually see the effect of increased bearing load.
Water in Oil	Strength	Not Applicable	Water can lead to a rapid failure. It is unlikely that a random monthly vibe scan would detect the anomaly.
Gear Wear	Strength	Strength	Vibration techniques can predict which gear. Lube analysis can predict the type of failure mode.
Alignment	Not Applicable	Strength	Vibration program can detect a misalignment condition. Lube analysis will eventually see the effect of increased / improper bearing load.
Lubricant Condition Monitoring	Strength	Not Applicable	The lubricant can be a significant cause of failure.
Resonance	Not Applicable	Strength	Vibration program can detect a resonance condition. Lube analysis will eventually see the effect.
Root Cause Analysis	Strength	Strength	Best when both programs work together.

Source: N. J. Kessissoglou and Z. Peng, "Integrating Vibration and Oil Analysis for Machine Condition Monitoring," Practicing Oil Analysis Magazine, March, 2003.

Approach & Rationale (*Cont.*)

- Combination of acoustic emission and vibration CM: extend the measurable dynamic frequency range to above 20 kHz.

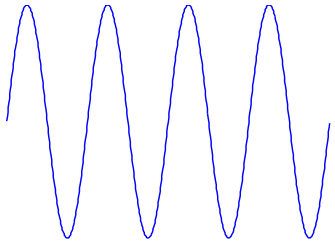
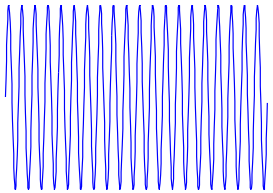
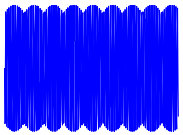
	Proximity probe*	Accelerometer**	Acoustic emission sensor***
Sensor			
Frequency	Low	Medium	High
			

Photo Sources:
** ProvibTech (with permission)*
*** PCB Piezotronics, Inc. (with permission)*
**** Physical Acoustics Corporation (with permission)*

Rationale (*Cont.*)

- Vibration measurement: proximity probes or accelerometers
- Proximity probes not considered: typically used for shaft displacement measurement, handled by GRC dynamics measurement
- Combine oil CM's active machine wear detection capability with AE and vibration CM's crack location pinpointing feature.

Options for Implementation

- Option 1
  - Customize needed sensors, data acquisition (DAQ) boards, and signal processing algorithms by NREL
- Option 2
  - Select a commercial package under each CM technique
  - Adopted: speed up implementation process and meet the planned GRC test schedule.

Selection Criteria

- Use one CM system from each technique category
- Choose the best possible package (in terms of performance) among interested CM participants
- Require previous experience in wind turbine CM.

Selected CM Systems

- High frequency range (>20 kHz) stress wave analysis: SwanSensor, SwanGuard, SwanServer and SwanView provided by SwanTech
- Medium to low frequency range (0.2 Hz ~ 10 kHz) vibration analysis: accelerometers, IMx-S & IMx-W, @ptitude and Microlog AX series provided by SKF
- Oil debris in ppm, moisture and oil condition: Online Sensor Suite provided by Kittiwake
- Ferrous and nonferrous particle counting: TechAlert 10 provided by Macom
- ISO 4406 oil cleanliness level monitoring: Hydac CSM 1220 provided by NREL as a lab unit.

Dynamics CM Systems

- SwanTech
  - One of the few commercial packages using ultrasonic range signals for CM
  - CM experience in wind industry.

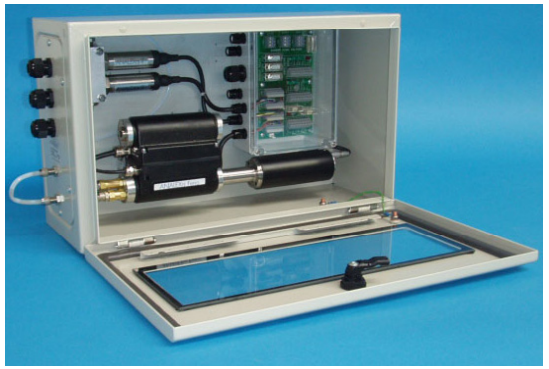
Source: SwanTech (with permission)

- SKF
  - One of the best vibration CM systems among interested participants
  - Huge bearing database benefited from being a main bearing supplier to wind turbines
  - CM experience in wind industry.

Source: SKF (with permission)

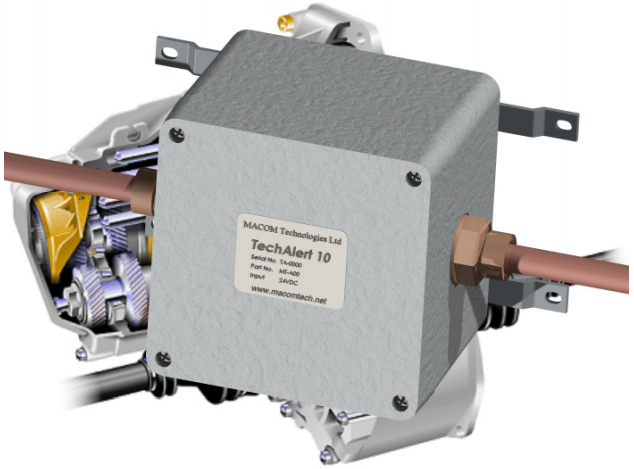
Oil CM Systems

- Kittiwake
  - Multiple parameters obtained by one compact package
  - No limitation on flow rates.



Source: Kittiwake (with permission)

- Macom
  - Five bins of both ferrous and non-ferrous particle sizes
  - Flow rate matches the kidney loop specifications.



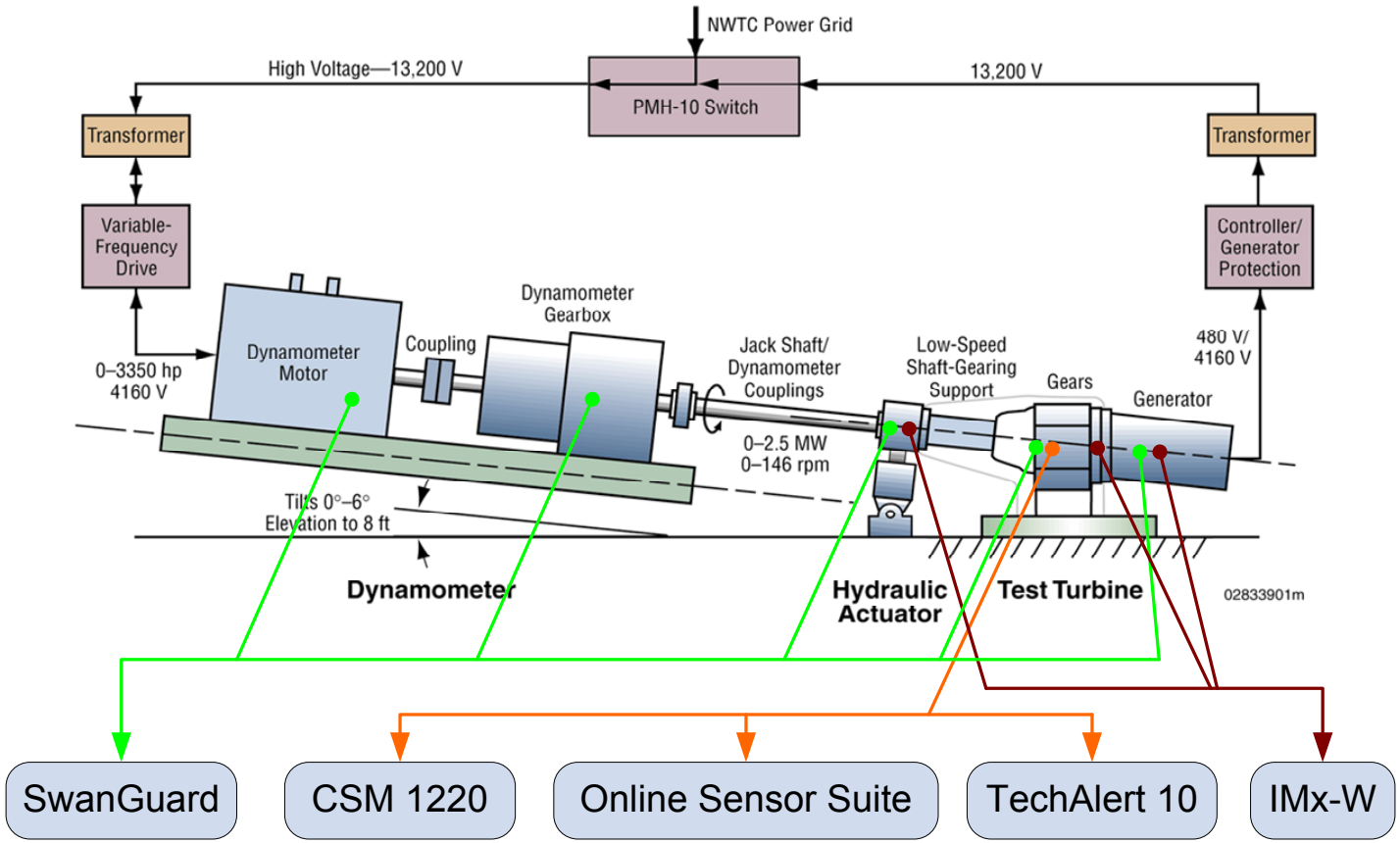
Source: Macom (with permission)

Source: Hydac (with permission)

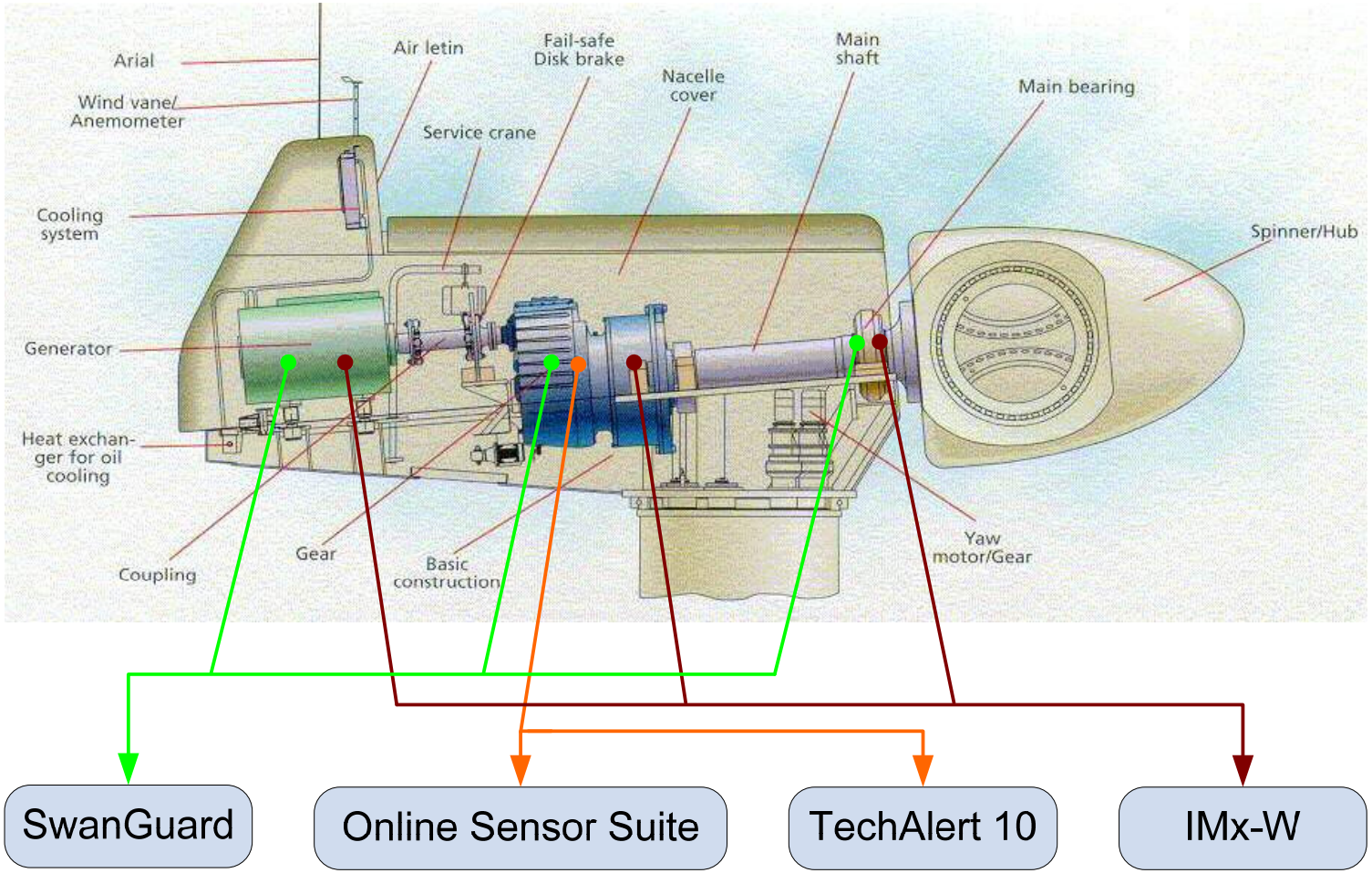
- Hydac
  - Provide ISO 4406 cleanliness level readings
  - Experience with lubricant Castrol OptiGear X320.

Implementation for Dyno Test

- Periodic oil sample analysis:
  - Obtain information not provided by oil CM systems and correlate with oil CM system readings.



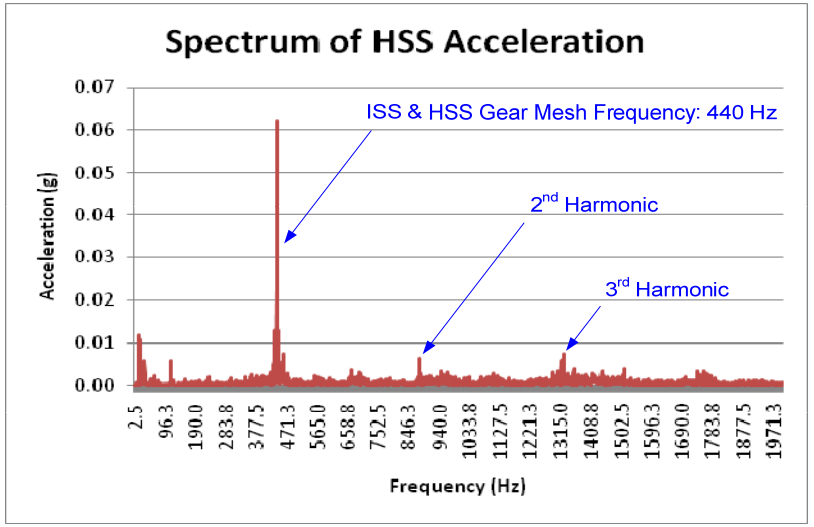
Planned Implementation for Field

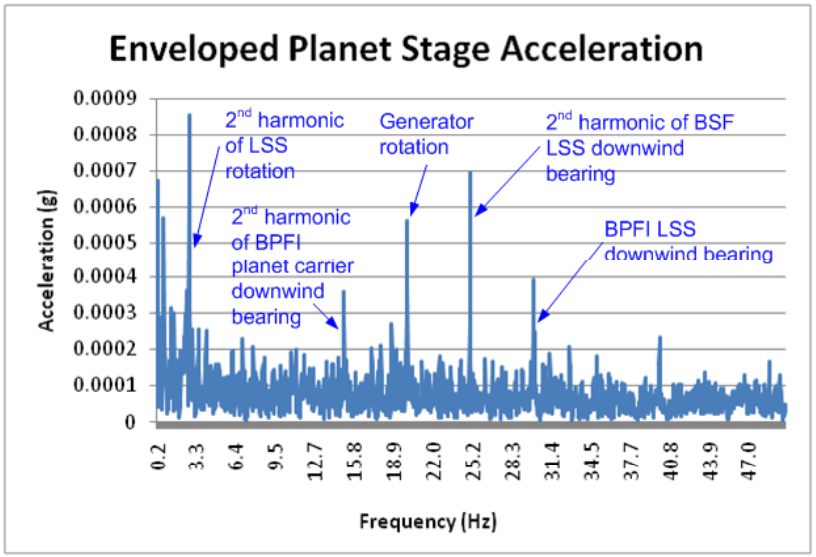


For both Dyno and field tests, most CM data remotely accessible using a web browser.

Preliminary Results: Vibration

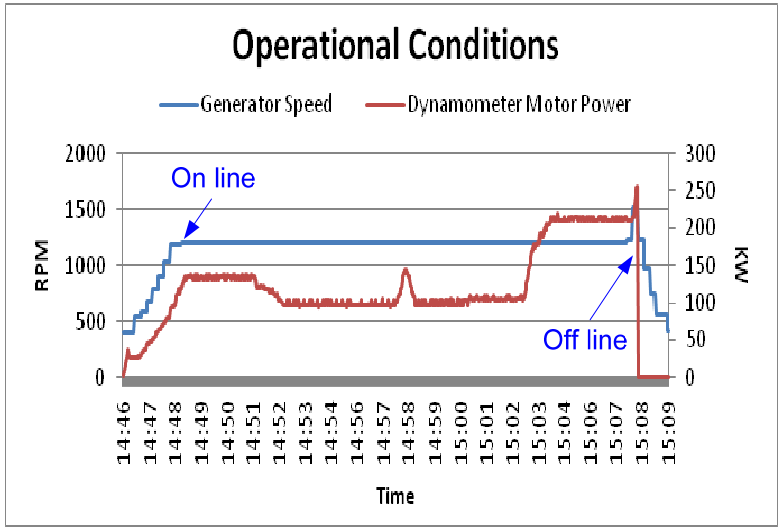
- Capable of detecting:
  - gear mesh, shaft rotational, bearing characteristic frequencies.
- Trending of these frequencies :
  - changes in condition of monitored components (e.g., bearing).

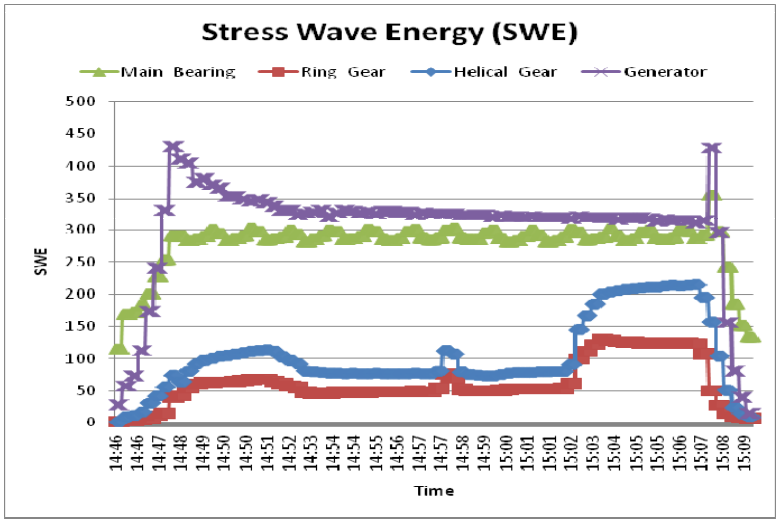




Preliminary Results: Stress Wave

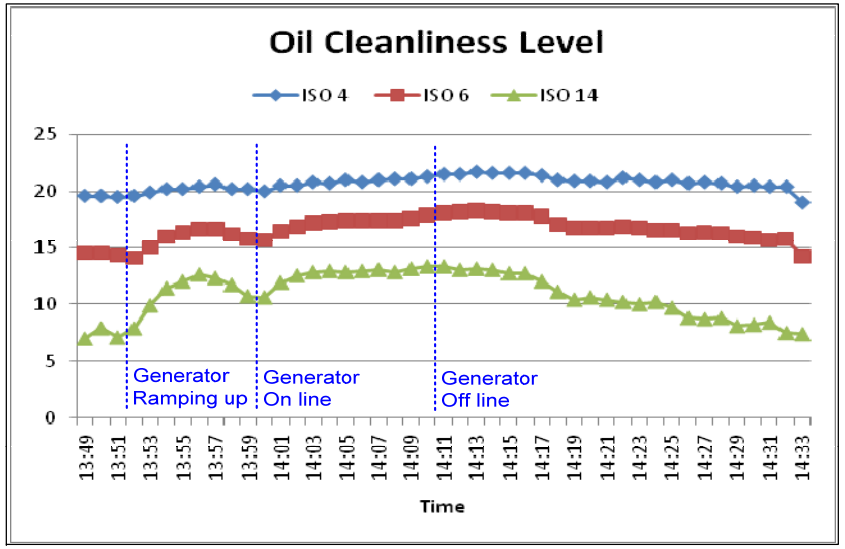
- Two pairs of strong correlations:
  - rpm with SWE at main bearing and generator
  - Dyno motor power and SWE at ring/helical gears.
- SWE might be useful for inferring driving load to the gearbox, if measurement is not available.





Preliminary Results: Oil

- A broad range of particles generated:
  - all three bins
  - wind turbine gearboxes always emit particles.



- Contamination level:
  - increases with ramping up of generator speed
  - decreases with shutdown of the generator and a continuously functional lubricant filtration system
  - might be useful as an indictor for run-in of gearboxes.
- Other oil CM systems:
  - No such subtle changes: might be designed for long-term operations, not applicable for run-in.

Planned Data Analysis

- Correlating abnormal CM indications with operational conditions and gearbox internal dynamics to trace possible root causes for certain failure modes
- Trending and comparing CM outputs from different techniques to gain a better understanding
- Correlating oil CM outputs with lab analysis results.

Future Research

- Investigate data fusion algorithms to integrate results obtained by each CM technique
- Investigate novel sensing mechanisms and signal processing algorithms for wind turbine CM
- Extend the present CM research to entire turbine and wind plant: first land-based, later offshore
- Investigate mechanisms for automatic delivery of useful information to turbine operators.

Wind Turbine CM Workshop

- Interested in attending or presenting:
  - Email: Shuangwen.Sheng@nrel.gov
  - Call: 303-384-7106
  - Pick up a post card: from the table at the end of the room.

Hope to see most of you at the CM workshop.

Thanks for your attention!

Special thanks to GRC CM participants: Kittiwake, Macom, SKF, SwanTech, and CC Jensen (Kidney Loop Filtration System Provider)!